



U.S. NUCLEAR REGULATORY COMMISSION

STANDARD REVIEW PLAN

3.5.3 BARRIER DESIGN PROCEDURES

REVIEW RESPONSIBILITIES

Primary - Organization responsible for structural analysis reviews

Secondary - None

I. AREAS OF REVIEW

The following areas are related to procedures utilized in the design of seismic Category I structures, shields, and barriers to withstand the effects of missile impact. These areas are reviewed to ensure conformance with 10 CFR 50, Appendix A, General Design Criterion (GDC) 2 and 4.

The specific areas of review are as follows:

1. Procedures utilized for the prediction of local damage in the impacted area. This includes estimation of the depth of penetration and, in case of concrete barriers, the potential for generation of secondary missiles by spalling or scabbing effects.
2. Procedures utilized for the prediction of the overall response of the barrier or portions thereof due to the missile impact. This includes assumptions on acceptable ductility ratios where elasto-plastic behavior is relied upon, and procedures for estimation of forces, moments, and shears induced in the barrier by the impact force of the missile.

Revision 3 - March 2007

USNRC STANDARD REVIEW PLAN

This Standard Review Plan, NUREG-0800, has been prepared to establish criteria that the U.S. Nuclear Regulatory Commission staff responsible for the review of applications to construct and operate nuclear power plants intends to use in evaluating whether an applicant/licensee meets the NRC's regulations. The Standard Review Plan is not a substitute for the NRC's regulations, and compliance with it is not required. However, an applicant is required to identify differences between the design features, analytical techniques, and procedural measures proposed for its facility and the SRP acceptance criteria and evaluate how the proposed alternatives to the SRP acceptance criteria provide an acceptable method of complying with the NRC regulations.

The standard review plan sections are numbered in accordance with corresponding sections in Regulatory Guide 1.70, "Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants (LWR Edition)." Not all sections of Regulatory Guide 1.70 have a corresponding review plan section. The SRP sections applicable to a combined license application for a new light-water reactor (LWR) are based on Regulatory Guide 1.206, "Combined License Applications for Nuclear Power Plants (LWR Edition)."

These documents are made available to the public as part of the NRC's policy to inform the nuclear industry and the general public of regulatory procedures and policies. Individual sections of NUREG-0800 will be revised periodically, as appropriate, to accommodate comments and to reflect new information and experience. Comments may be submitted electronically by email to NRR_SRP@nrc.gov.

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3. The adequacy of missiles' parameters cited in support of the applicant's conclusions concerning their suitability for the plant and the effects of missiles on structures, systems, and components (SSCs). The staff also reviews the missiles parameters as an integral part of structural analysis.
4. Inspections, Tests, Analyses, and Acceptance Criteria (ITAAC). For design certification (DC) and combined license (COL) reviews, the staff reviews the applicant's proposed ITAAC associated with the SSCs related to this SRP section in accordance with SRP Section 14.3, "Inspections, Tests, Analyses, and Acceptance Criteria." The staff recognizes that the review of ITAAC cannot be completed until after the rest of this portion of the application has been reviewed against acceptance criteria contained in this SRP section. Furthermore, the staff reviews the ITAAC to ensure that all SSCs in this area of review are identified and addressed as appropriate in accordance with SRP Section 14.3.
5. COL Action Items and Certification Requirements and Restrictions. For a DC application, the review will also address COL action items and requirements and restrictions (e.g., interface requirements and site parameters).

For a COL application referencing a DC, a COL applicant must address COL action items (referred to as COL license information in certain DCs) included in the referenced DC. Additionally, a COL applicant must address requirements and restrictions (e.g., interface requirements and site parameters) included in the referenced DC.

Review Interfaces

Other SRP sections interface with this section as follows:

1. The adequacy of missile parameters cited in support of the applicant's conclusions concerning their suitability for the plant are reviewed in accordance with SRP Sections 3.5.1.1, 3.5.1.2, 3.5.1.4, 3.5.1.5, and 3.5.1.6.
2. The adequacy of turbine missile parameters cited in support of the applicant's conclusions concerning their suitability for the plant are reviewed in accordance with SRP Section 3.5.1.3.
3. The review of the SSCs to be protected from externally-generated missiles includes all plant site safety-related SSCs supporting the reactor facility is reviewed in accordance with SRP Section 3.5.2.

The specific acceptance criteria and review procedures are contained in the referenced SRP sections.

II. ACCEPTANCE CRITERIA

Requirements

Acceptance criteria are based on meeting the relevant requirements of the following Commission regulations.

The design of structures, shields, and barriers be such that these can withstand the effects of environmental and natural phenomena to be in conformance with requirements of GDC 2 and 4. The relevant requirements are as follows:

1. GDC 2 requires that SSCs important to safety shall be designed to withstand the effects of natural phenomena such as earthquakes, tornados, hurricanes, tsunami, floods, and seiches without loss of capability to perform their safety functions as it relates to natural phenomena. The design bases for these SSCs shall reflect appropriate combinations of the effects of normal and accident conditions with the effects of the natural phenomena.
2. GDC 4 requires that SSCs important to safety shall be appropriately protected against dynamic effects, including the effects of missiles, pipe whipping, and discharging fluids that may result from equipment failures and from events and conditions outside the nuclear power unit.
3. 10 CFR 52.47(b)(1), which requires that a DC application contain the proposed inspections, tests, analyses, and acceptance criteria (ITAAC) that are necessary and sufficient to provide reasonable assurance that, if the inspections, tests, and analyses are performed and the acceptance criteria met, a plant that incorporates the design certification is built and will operate in accordance with the design certification, the provisions of the Atomic Energy Act, and the NRC's regulations;
4. 10 CFR 52.80(a), which requires that a COL application contain the proposed inspections, tests, and analyses, including those applicable to emergency planning, that the licensee shall perform, and the acceptance criteria that are necessary and sufficient to provide reasonable assurance that, if the inspections, tests, and analyses are performed and the acceptance criteria met, the facility has been constructed and will operate in conformity with the combined license, the provisions of the Atomic Energy Act, and the NRC's regulations.

SRP Acceptance Criteria

Specific SRP acceptance criteria acceptable to meet the relevant requirements of the NRC's regulations identified above are as follows for the review described in this SRP section. The SRP is not a substitute for the NRC's regulations, and compliance with it is not required. However, an applicant is required to identify differences between the design features, analytical techniques, and procedural measures proposed for its facility and the SRP acceptance criteria and evaluate how the proposed alternatives to the SRP acceptance criteria provide acceptable methods of compliance with the NRC regulations.

Specific criteria necessary to meet the relevant requirements of GDC 2 and 4 are as follows:

1. For Local Damage Prediction

A. Concrete

Sufficient thickness of concrete should be provided to prevent perforation, spalling, or scabbing of the barriers in the event of missile impact.

Several empirical equations, such as the modified National Defense Research Council (NDRC) formula; proposed in "A Review of Procedures for the Analysis and Design of Concrete Structures to Resist Missile Impact Effects," by R.P. Kennedy, Nuclear Engineering and Design 1976 Pages 183-203 are available to estimate missile penetration into concrete. These equations should be used to determine the required barrier thicknesses. Thicknesses resulting from such

calculations should not be less than those listed in Table 1, which specifies the minimum thicknesses necessary to protect against tornado missiles.

Table 1, Minimum Acceptable Barrier Thickness Requirements, provides minimum concrete barrier thickness requirements for preventing local damage against tornado generated missiles for tornado spectrum shown in Table 2 of Regulatory Guide (RG) 1.76.

Barrier thicknesses less than those listed in Table 1 may be used, provided that sufficient justification (including test data) is presented to support them. These justification will be reviewed on a case-by-case basis.

Other types of missiles are specified in SRP Sections 3.5.1.1 through 3.5.1.6.

For turbine missile barriers, penetration and scabbing predictions should be based on empirical equations such as the modified NDRC formula or the results of a valid test program.

B. Steel

The results of tests conducted by the Stanford Research Institute (SRI) on the penetration of missiles into steel plates are summarized in "U.S. Reactor Containment Technology" (ORNL/NSIC-5, Vol.1, Chapter 6, Oak Ridge National Laboratory, 1965) by W.B. Cottrell and A.W. Savolainen. The equations presented in aforementioned document are acceptable. Other equations such as the Ballistic Research Laboratory formula described in, "Reactor Safeguards," by C. R. Russell, published by MacMillan, New York, 1962, may be used, provided the results are either comparable to those obtained by using the aforementioned "U.S. Reactor Containment Technology" method or are validated by penetration tests.

C. Composite Sections

For composite or multi-element barriers, procedures for prediction of local damage are acceptable if the residual velocity of the missile perforating the first element is considered as the striking velocity for the next element. For determining this residual velocity, the equations presented in "Ballistic Perforation Dynamics," Journal of Applied Mechanics, Transactions of the ASME, Vol. 30, Series E, No. 3, September 1963 by R. F. Recht and T. W. Ipson, are acceptable when the first barrier of a multi-element missile barrier is steel. When the first barrier is concrete, procedures used are reviewed on a case-by-case basis.

TABLE 1
Minimum Acceptable Barrier Thickness Requirements
For Local Damage Prediction Against Tornado Generated Missiles

Regions*	Concrete Strength MPa (psi)	Wall Thickness cm (inches)	Roof Thickness cm (inches)
Region I	20.7 (3000) 27.6 (4000) 34.5 (5000)	46.2 (18.2) 42.9 (16.9) 40.6 (16.0)	33.5 (13.2) 31.2 (12.3) 29.7 (11.7)
Region II	20.7 (3000) 27.6 (4000) 34.5 (5000)	39.1 (15.4) 36.3 (14.3) 34.5 (13.6)	28.4 (11.2) 26.4 (10.4) 25.1 (9.9)
Region III	20.7 (3000) 27.6 (4000) 34.5 (5000)	30.2 (11.9) 28.2 (11.1) 26.7 (10.5)	22.1 (8.7) 20.6 (8.1) 19.6 (7.7)

*
For definition of Regions I, II, and III, refer to RG 1.76

2. For Overall Damage Prediction

The response of a structure or barrier to missile impact depends largely on the location of impact (e.g., midspan of a slab or near a support), on the dynamic properties of the target and missile, and on the kinetic energy of the missile. In general, the assumption of plastic collisions is acceptable, where all of the missile's initial momentum is transferred to the target and only a portion of its kinetic energy is absorbed as strain energy within the target. However, where elastic impacts are expected, the additional momentum transferred to the target by missile rebound should be considered in the analyses.

After it has been demonstrated that the missile will not penetrate the barrier, an equivalent static load concentrated at the impact area should then be determined, from which the structural response, in conjunction with other design loads, can be evaluated using conventional design methods. An acceptable procedure for such an analysis, where the impact is assumed to be plastic, is presented in "Impact Effect of Fragments Striking Structural Elements," Holmes and Narver, Inc., Revised November 1973 by R. A. Williamson and R. R. Alvy. Other procedures may be used, with adequate justification provided the results obtained are comparable to that of the above reference.

Maximum allowable ductility ratios for steel and reinforced concrete barriers, in the above analysis, are given in American National Standard Institute/ American Institute of Steel Construction (ANSI/AISC) N690-1994 including supplement 2(2004), American National Standard Specification for the Design, Fabrication, and Erection of Steel Safety-Related Structures for Nuclear Facilities (1994) and in RG 1.142. respectively.

Technical Rationale

The technical rationale for application of these acceptance criteria to the areas of review addressed by this SRP section is discussed in the following paragraphs:

1. Compliance with GDC 2, "Design Bases for Protection Against Natural Phenomena," requires that SSCs important to safety shall be designed to withstand (or be protected against) the effects of natural phenomena without loss of capability to perform their safety functions. The design bases for such SSCs must include consideration of the importance of their safety functions, and the effects of accident conditions and natural phenomena.

The staff's criteria for the design of missile barriers provide for protecting SSCs from missiles generated by natural phenomena and other events. The criteria consider natural phenomena that occur concurrently with accident conditions.

Meeting the requirements of GDC 2 provides a level of assurance that SSCs important to safety will be protected against missile and accident effects caused by natural phenomena and will thus be capable of performing its intended safety function.

2. Compliance with GDC 4, "Environmental and Dynamic Effects Design Bases," requires SSCs important to safety shall be designed to accommodate the effects of, and be compatible with, environmental conditions associated with normal operation, maintenance, testing, and postulated accidents, including loss-of-coolant accidents.

Ensuring the adequacy of such SSCs includes protecting against the effects of missiles, pipe whipping, and discharging fluids that may result from equipment failures and from events and conditions outside the nuclear power unit.

SRP Section 3.5.3 includes the staff's criteria for providing adequate barriers design to resist missiles, pipe whipping, and the discharging fluids in order to protect structures, systems, and components important to safety. These criteria are based on sound engineering principles, experience, and test results.

Meeting the requirements of GDC 4 by providing barrier against the effects of missiles, pipe whipping, and discharging fluids provides a level of assurance that structures, systems, and components important to safety will be capable of performing their intended safety function.

III. REVIEW PROCEDURES

The reviewer will select material from the procedures described below, as may be appropriate for a particular case.

These review procedures are based on the identified SRP acceptance criteria. For deviations from these acceptance criteria, the staff should review the applicant's evaluation of how the proposed alternatives provide an acceptable method of complying with the relevant NRC requirements identified in Subsection II.

1. For the prediction of local damage, the equations proposed by the applicant for estimation of missile penetration are reviewed in the following manner:
 - A. For missile penetration in concrete, the reviewer verifies that the applicant has used the empirical formulas such as the modified NDRC formula or valid test results. The reviewer also verifies that the applicant has provided sufficient barrier thickness to prevent perforation and to prevent spalling or scabbing when protection from spalling or scabbing is considered necessary.
 - B. For missile penetration in steel, the reviewer verifies that the applicant has used the SRI equations as referred to in Subsection II. 1(B) of this SRP. If other equations are selected, adequate justification with the applicability and validity of such equations are reviewed to ensure that the results are comparable to those obtained from the aforementioned SRI equations.
 - C. For missile penetration in composite or multi-element barriers, the reviewer verifies that the applicant has used the criteria delineated in Section II Acceptance Criteria, "SRP Acceptance Criteria" subsection 1.C of this SRP. If other criteria are proposed, the justification provided is reviewed to ensure that such equations give results which are comparable to those in "SRP Acceptance Criteria" subsection 1.C.
2. For the prediction of overall damage and response of the barrier, the reviewer verifies that the applicant has used the criteria delineated in subsection II.2 of this SRP. If other criteria are selected, the applicant's justification is reviewed to ensure that the

results obtained are at least equivalent to those obtained by using method delineated in subsection II.2.

3. Refer to SRP Section 3.5.1.3, "Turbine Missiles," for additional information regarding the protection of SSCs from the effects of turbine missiles.
4. For review of a DC application, the reviewer should follow the above procedures to verify that the design, including requirements and restrictions (e.g., interface requirements and site parameters), set forth in the final safety analysis report (FSAR) meets the acceptance criteria. DCs have referred to the FSAR as the design control document (DCD). The reviewer should also consider the appropriateness of identified COL action items. The reviewer may identify additional COL action items; however, to ensure these COL action items are addressed during a COL application, they should be added to the DC FSAR.

For review of a COL application, the scope of the review is dependent on whether the COL applicant references a DC, an early site permit (ESP) or other NRC approvals (e.g., manufacturing license, site suitability report or topical report).

For review of both DC and COL applications, SRP Section 14.3 should be followed for the review of ITAAC. The review of ITAAC cannot be completed until after the completion of this section.

IV. EVALUATION FINDINGS

The reviewer verifies that the applicant has provided sufficient information and that the review and calculations (if applicable) support conclusions of the following type to be included in the staff's safety evaluation report. The reviewer also states the bases for those conclusions.

The staff concludes that the barrier design is acceptable and meets the requirements of GDC 2 and 4 with respect to the capabilities of the structures, shields, and barriers to provide sufficient protection to SSCs that must withstand the effects of natural phenomena (tornado missiles) and environmental effects including the effects of missiles, pipe whipping, and discharging fluids. This conclusion is based on the following:

The procedures utilized to determine the effects and loadings on seismic Category I structures and missile shields and barriers induced by design basis missiles selected for the plant are acceptable since these procedures provide an adequate basis for engineering design to ensure that the structures or barriers are adequately resistant to and will withstand the effects of such forces.

The use of these procedures provides reasonable assurance that in the event of design basis missiles striking seismic Category I structures or other missile shields and barriers, the structural integrity of the structures, shields, and barriers will not be impaired or degraded to an extent that will result in a loss of required protection. Seismic Category I SSCs protected by these barriers are, therefore, adequately protected against the effects of missiles and will perform their intended safety functions. Conformance with these procedures is an acceptable basis for satisfying in part the requirements of GDC 2 and 4.

For DC and COL reviews, the findings will also summarize the staff's evaluation of requirements and restrictions (e.g., interface requirements and site parameters) and COL action items relevant to this SRP section.

In addition, to the extent that the review is not discussed in other SER sections, the findings will summarize the staff's evaluation of the ITAAC, including design acceptance criteria, as applicable.

V. IMPLEMENTATION

The staff will use this SRP section in performing safety evaluations of DC applications and license applications submitted by applicants pursuant to 10 CFR Part 50 or 10 CFR Part 52. Except when the applicant proposes an acceptable alternative method for complying with specified portions of the Commission's regulations, the staff will use the method described herein to evaluate conformance with Commission regulations.

The provisions of this SRP section apply to reviews of applications submitted six months or more after the date of issuance of this SRP section, unless superseded by a later revision.

VI. REFERENCES

1. 10 CFR Part 50, Appendix A, General Design Criterion 2, "Design Bases for Protection Against Natural Phenomena."
2. 10 CFR Part 50, Appendix A, General Design Criterion 4, "Environmental and Dynamic Effects Design Bases."
3. R. P. Kennedy, "A Review of Procedures for the Analysis and Design of Concrete Structures to Resist Missile Impact Effects," Nuclear Engineering and Design. Volume 37, Number 2. 183-203. 1976.
4. W. B. Cottrell and A. W. Savolainen, "U.S. Reactor Containment Technology," ORNL NSIC-5, Ridge National Laboratory, Oak Ridge, TN: Volume 1, Chapter 6. 1965.
5. C. R. Russell, "Reactor Safeguards," New York: MacMillan. 1962.
6. R. F. Recht and T. W. Ipson, "Ballistic Perforation Dynamics," ASME Journal of Applied Mechanics. Volume. 30, Series E, Number 3. September 1963.
7. R. A. Williamson and R. R. Alvy, "Impact Effect of Fragments Striking Structural Elements," Holmes and Narver, Inc: Anaheim, CA. 1973.
8. Regulatory Guide 1.76, "Design Basis Tornado for Nuclear Power Plants."
9. American Institute of Steel Construction. Specification for the Design, Fabrication, and Erection of Steel Safety-Related Structures for Nuclear Facilities. ANSI/AISC N690. American Institute of Steel Construction: Chicago, IL. 1994.

10. Regulatory Guide 1.142, "Safety-Related Concrete Structures for Nuclear Power Plants (Other Than Reactor Vessels and Containments)."

PAPERWORK REDUCTION ACT STATEMENT

The information collections contained in the Standard Review Plan are covered by the requirements of 10 CFR Part 50 and 10 CFR Part 52, and were approved by the Office of Management and Budget, approval number 3150-0011 and 3150-0151.

PUBLIC PROTECTION NOTIFICATION

The NRC may not conduct or sponsor, and a person is not required to respond to, a request for information or an information collection requirement unless the requesting document displays a currently valid OMB control number.
